‘Life Cycle Assessment of an axial air compressor manufactured by the firm FINI COMPRESSORI’

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ABSTRACT

This study was performed jointly by ENEA (Italian National Agency for New Technologies, Energy and Environment), Bologna and Florence Universities and the firm FINI COMPRESSORI. The functional unit is an axial air compressor manufactured by FINI COMPRESSORI, lubricated, having a 25-litres air tank, provided by 1.8 kW electrical motor. The system boundaries include raw material extraction and the end of life of the compressor. All metallic materials have the recycling as waste scenario. The LCA is obtained by using the SimaPro 3.1 code and the two methods Eco-indicator 95 and Ecopoints.

The results show that air tank and stator of electrical motor are the components with greater environmental damage, even if the damage is mainly due to the electrical energy consumed during use. The most important categories of damage produced by the air tank are carcinogenic substances, heavy metals and acidification due to the material and processes used for its manufacturing and the ones produced by aluminium part of stator are acidification and winter smog due to material manufacturing.

To reduce the damage of air compressor we have proposed some design solutions to lower air temperature in cylinder and at collector outlet.

Key-words: Life Cycle Assessment, Air compressor, Eco-indicator, Ecopoint

1. INTRODUCTION

This study was performed jointly by ENEA, Bologna and Florence Universities and the firm FINI COMPRESSORI[1].
By means of the Life Cycle Assessment we have calculated the environmental damage of a coaxial air compressor CORSAIR 282 manufactured by the firm FINI COMPRESSORI. This model has the following characteristics:

- the electrical power: 1.8 kW
- the maximum pressure: 10 bar
- the volume of the air tank: 25 l
- the volume of the air sucked up: 139 l/min

The study has been also carried out in accordance with the ISO/DIS 14040 norm.

2. DEFINITION OF AIMS AND BOUNDARIES OF THE STUDY.

The study has the **goal** of evaluating the environmental damage caused by production, use and disposal of an air compressor, and of proposing possible innovative solutions to reduce the damage.
The **system** to be studied is the production of a force or a moment by using compressed air.
The **functional unit** is represented by a coaxial air compressor model CORSAIR 282, oil lubricated, composed by

- steel sheet 25 litres tank,
- aluminium alloy piston
- aluminium cylinder provided by pressed-in steel liner.

It’s a product mainly used for hobby activities and by small firms. We have assumed that his average life is 10 years. In order to consider scraps connected with components manufacturing, estimated equal to 2% of the total weight, we have multiplied the material quantities by the factor 1.02.
The **boundaries** of the study include the extraction of the minerals and fuels and the end of life of the compressor components. We have not considered machines and tools for the component production.
The **data** have the following characteristics:

- many data are not lied to a geographic area, other are lied to Europe and to Holland.
- In order to simplify the study, we have also chosen to use only the data included in the code database.

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- The methods used are reproducible but do not consider all the emitted substances.
- The databases are IDEMAT 96 and PRé.

The LCA study is performed by using SimaPro 3.1[2] code and the method Eco – indicator 95 Europe g. For comparison we have used also the Ecopoints method.

3. LIFE CYCLE INVENTORY ANALYSIS.

The study is conducted by using the following criteria:

1. we consider the production and the transport of the raw materials used by the component manufacturers.
2. We consider the single components production, taking into account the weight, the amount of transport from the manufacturers to the firm and the production processes of every component. We not consider possible others auxiliary materials used during the component production.
3. Inside FINI firm we examine the phases of assembling, tank painting and packaging and we consider the use of auxiliary materials as loctite and teflon.
4. We consider the service to the customers, by doing an average evaluation of the transports.
5. We assume a compressor average life of 10 years
6. Every component disposal is evaluated by considering the various materials which compose the compressor component. For the disposal scenario we do the following assumptions:
   - the compressor is withdrawn by a specialised firm.
   - Metallic components are separated from the plastic ones.
   - Metallic components are recycled.
   - Non metallic components, mainly plastics, are incinerated.
   - When plastic parts are intimately connected with metallic parts (for example the tap is mainly composed by nickel-plated steel, but the handgrip is composed by PVC) we have chosen the recycle of the metallic parts. In this way the plastic materials are subjected to a process similar to the incineration but without heat production.

The compressor has been subdivided into two parts:

- compression group (Fig.1)

- tank group (Fig.2)

Impact assessment has been evaluated by considering all the components. For everyone we have collected data regarding materials, processes and transports that we have represented by data drawn from the code SimaPro database. Fig.3 shows the flow-chart of the life cycle of the compressor.

Fig.1 The compression group.

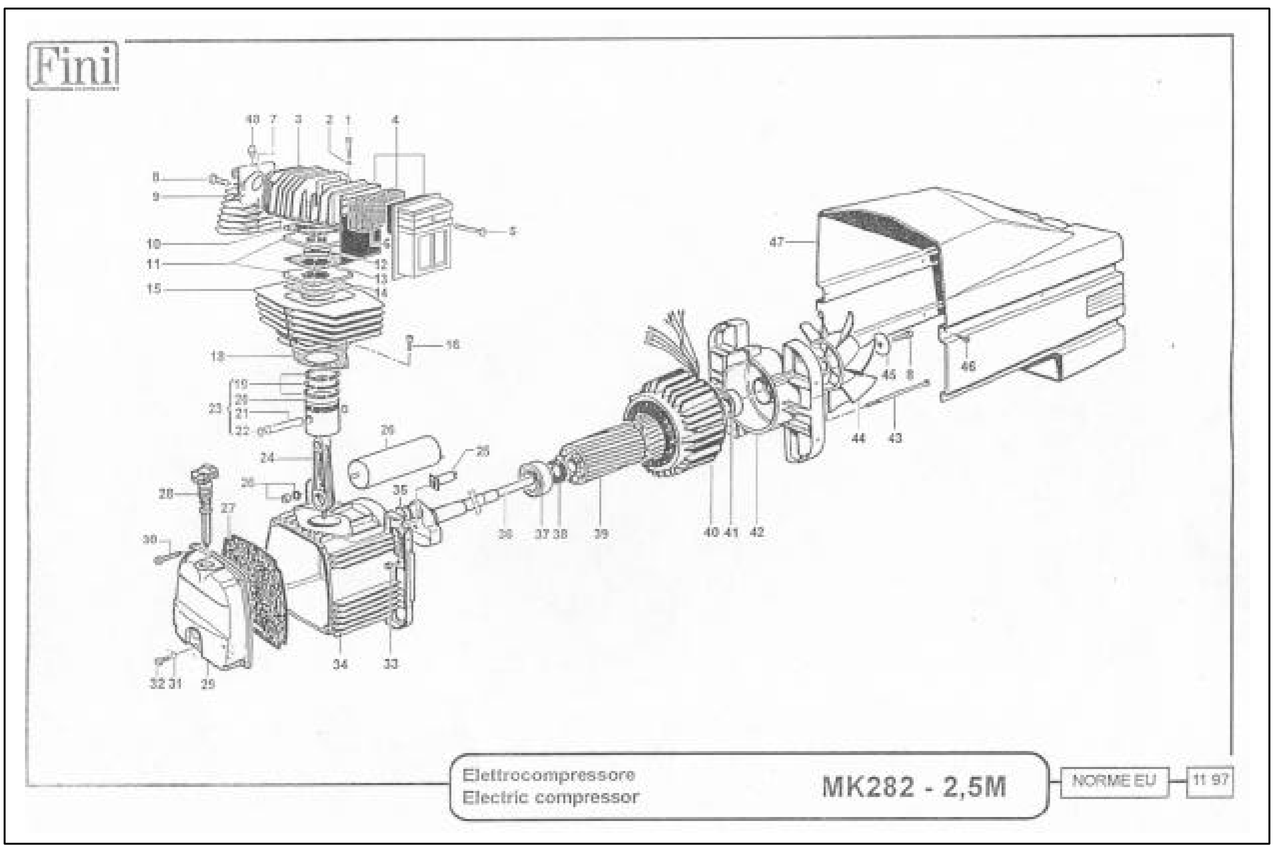


Fig.2 The tank group.

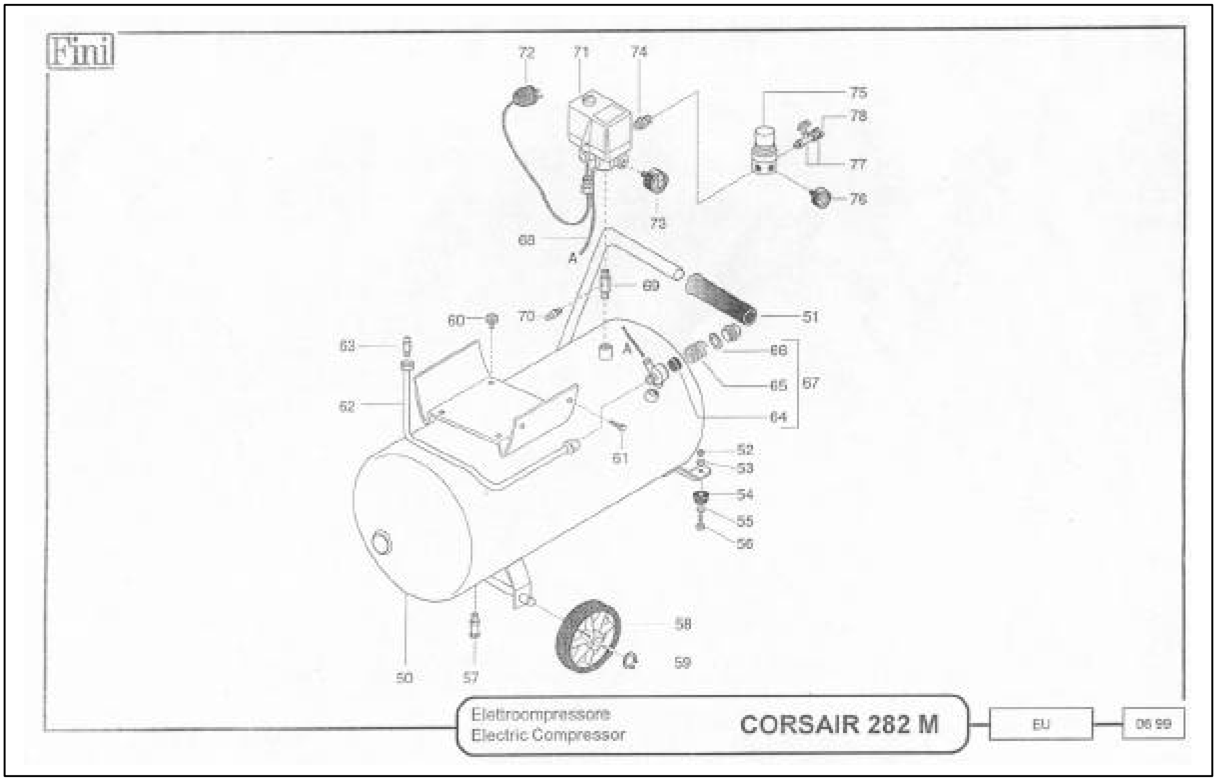
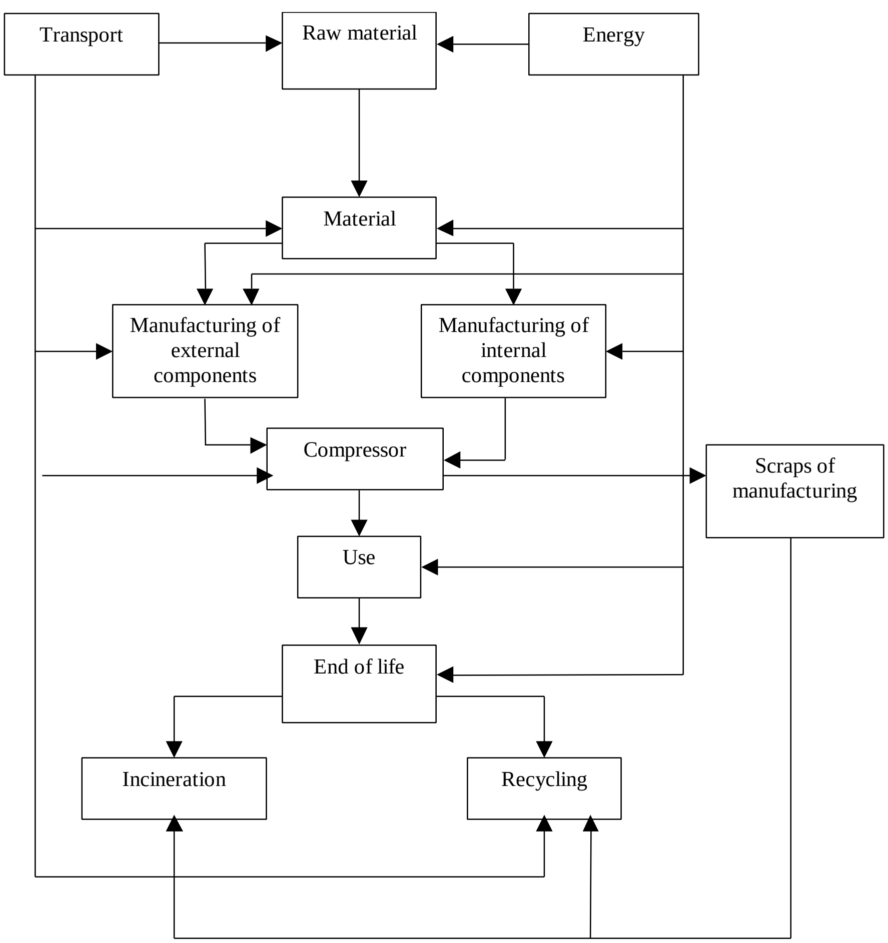


Fig.3 The flow-chart of the life cycle of the compressor.



3.1. Waste treatment

- For the metals we have considered the recycling as end life scenario.
- For the recycling of the non ferrous metals with 'Disposal fraction' copper, magnesium, zinc, e non ferrous, we have chosen Zinc I as the 'avoided product', because it is the non ferrous metal that produces the lesser damage. In this way we have the lower advantage connected with the recycling.
- The end of life of plastic component is the incineration.
- For the components with plastic parts intimately connected with metallic parts we have created a 'Waste Scenario' which considers the recycling for the metals and the incineration without energy recovery for the plastics parts which burn during metal casting.
- In order to describe lubrication oil we have created the 'material' crude oil B1 modifying the crude oil B one by the data provided by FINI. We have supposed that 10% draws out from trimmings and goes directly in environment and that the 90% is collected and incinerated.

3.2. Transports.

We refer to three different kinds of transports:

- component transports. In the LCA of each component we have applied the process 'transport' Truck long distance C to the transport from the manufacturer to FINI and the transport for the purveying of the materials used in component production.
- Distribution transports. We have considered the firm information concerning the sales in Italy and the exports: the 30% of production is sold in Italy, the 78.8% of the sold abroad production is distributed in Europe. To the transports in Italy and in Europe we have applied the process 'transport' Truck I. To the exports to Australia we have applied the process 'transport' Air traffic int, while to the exportations to Taiwan and Indonesia we have applied the process 'transport' Deep sea vessel.
- Maintenance transports. We have supposed that the compressor during its life needs of one maintenance service for which we have applied the process 'transport' Truck long distance C.

Tab.1 shows some characteristics of the used types of transport.

Tab.1 The 'transports' used for LCA calculation.

Type of transport	Fuel	Weight [kg]	Mass * distance [tkm]
Truck I	Diesel I	0.28	13.8
Truck long distance C	Crude diesel	0.0235	1
Air traffic int.	Kerosene	0.352	1
Deep sea vessel	Crude diesel	0.0047	1

3.3. Electric energy consumption.

- *Energy required to produce the components.*
  This energy is included in the processes to obtain the single component.
- *Energy used in the component assembling.*
  FINI firm takes care only of the assembling of the following parts:
  - compression group
  - pressure switch/reducer group
  - tank group
  For assembling we have estimated an energy consumption of 1 kWh for each functional unit.
- *Energy used to paint the tank.*
  FINI uses a paint composed by epoxypolyester powder polymerized in furnace at 180 °C. Energy consumed in this phase has been estimated in 1kWh for each 25 l tank.
- *Energy used by indirect centres.*
  It is the energy used for heating, lighting etc. On the basis of data related to the firm, we have calculated that for each functional unit the energy consumed is 1.157 kWh
- *Energy used during running in.*
  In this phase we have supposed that each group consumes 0.46 kWh.
- *Energy used during use.*
  We start from the project data of the electrical engine. We assume that the functional unit is used for 2 hours in every day during 280 days in every year for a total of 10 years. Because the environmental damages due to the electrical energy production depend upon the types of fuel used by each State, we have created a new process 'energy' that considers its consumption on the basis of exports.

3.4. Life cycle analysis by the Eco-indicator 95 Europe g method.

The life cycle analysis has been performed by means of the calculation code SimaPro 3.1, using the Eco-indicator 95 Europe g.

For every component described in the inventory we have calculated a LCA which has been included in the LCA of the two main groups of components as ‘additional life cycle’. Finally we have created the total LCA that considers:

- the LCA of the two main groups
- the electricity for component assembling
- the electricity for use
- LCA of auxiliary material
- LCA of the packaging

Tab.2 shows the results.

Tab.2 LCA of the compressor by the Eco-indicator method.

CHARACTERISATION			
Damage categories	**Values**	**Emissions**	**Damage causes and components**
Compression group			
Energy	475 MJ	-	Metal production and processes for stator and rotor
Greenhouse	43.4 kg	CO_2	Metal production for stator, rotor and cylinder
Solid	13.7 kg	Generic solid waste	Material production for stator, conveyor and cylinder
Tank group			
Energy	87.4 MJ	-	Production of paint and roads and feeding cable
Greenhouse	21.9 kg	CO_2	Material production for tank, roads and feeding cable
Solid	8.18 kg	Generic solid waste	Copper production for feeding cable
NORMALISATION			
Damage categories	**Values**	**Emissions**	**Damage causes and components**
Compression group			
Heavy Metals	$7.9*10^{-4}$	Pb and Cd	Metal production and casting process for stator and bearings
Energy	$3*10^{-4}$	-	Metal production and processes for stator and rotor
Greenhouse	$3.6*10^{-4}$	CO_2	Metal production for stator, rotor and tank
Tank group			
Heavy Metals	$9.3*10^{-4}$	Cd	Metal production for tank and pressure switch and casting process for drain cock
Carcinogenic substances	$2.8*10^{-4}$	Benzene PAH Ni e As	Metal production for tank and pressure switch
Acidification	$2.6*10^{-4}$	SO_2, NO_x, SO_x	Material production for tank and feeding cable
EVALUATION			
Damage categories	**Values**	**Emissions**	**Damage causes and components**
Compression group			
Heavy Metals	3.93 mPt	Pb and Cd	Metal production and casting process for stator and bearings
Acidification	1.76 mPt	SO_2,NO_x, SO_x	Metal production and processes for crankshaft, rotor and crankcase
Winter Smog	1.01 mPt	SO_2 and dust (SPM)	Metal production for stator and rotor
Tank group			
Heavy Metals	4.63 mPt	Cd	Metal production for tank and pressure switch and casting process for drain cock
Carcinogenic substances	2.8 mPt	Benzene PAH Ni e As	Metal production for tank and pressure switch
Acidification	2.59 mPt	SO_2, NO_x, SO_x	Material production for tank and pressure switch

The components that produce the greater values of damage are the tank for the tank group and the stator for the compression group. The Fig.4 and 5 show the evaluation of their assemblies obtained by the Eco-indicator 95 method.

Fig.4 Evaluation by the Eco-indicator 95 method of the 'assembly' of the aluminium part of the stator of the electrical motor.

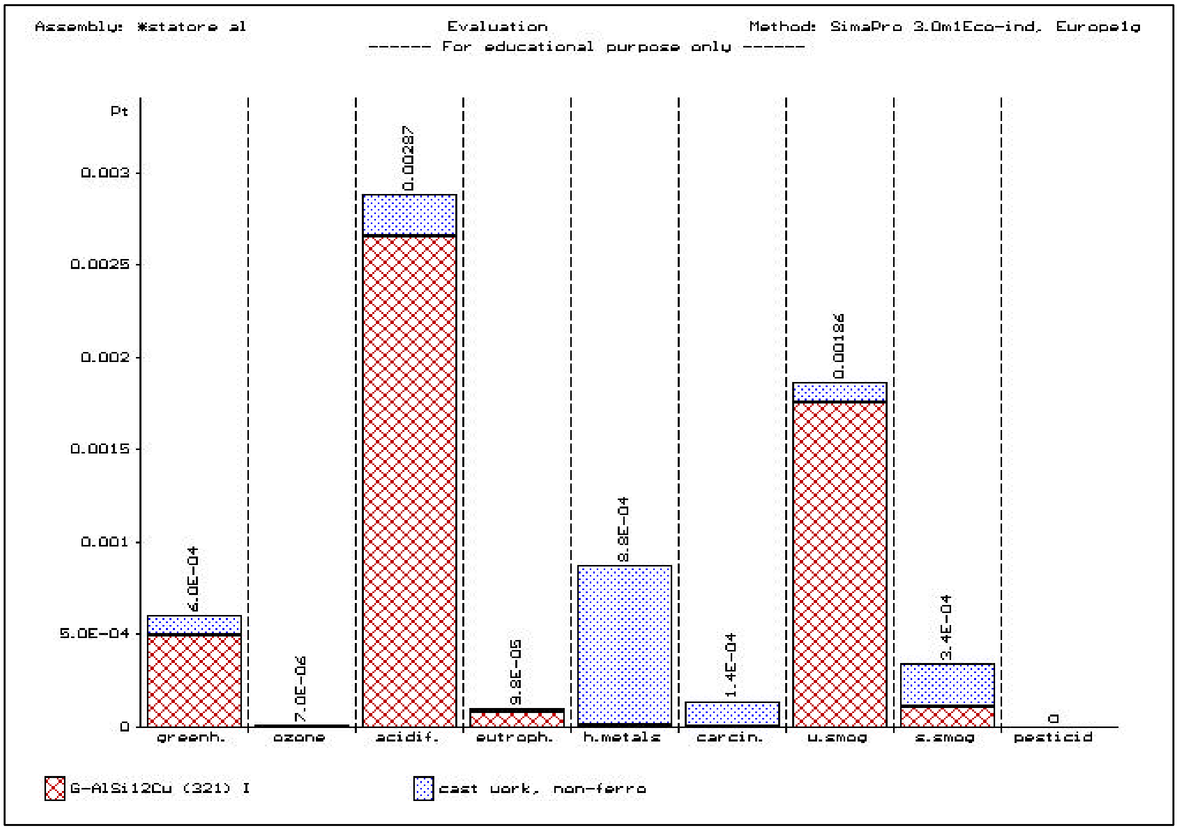
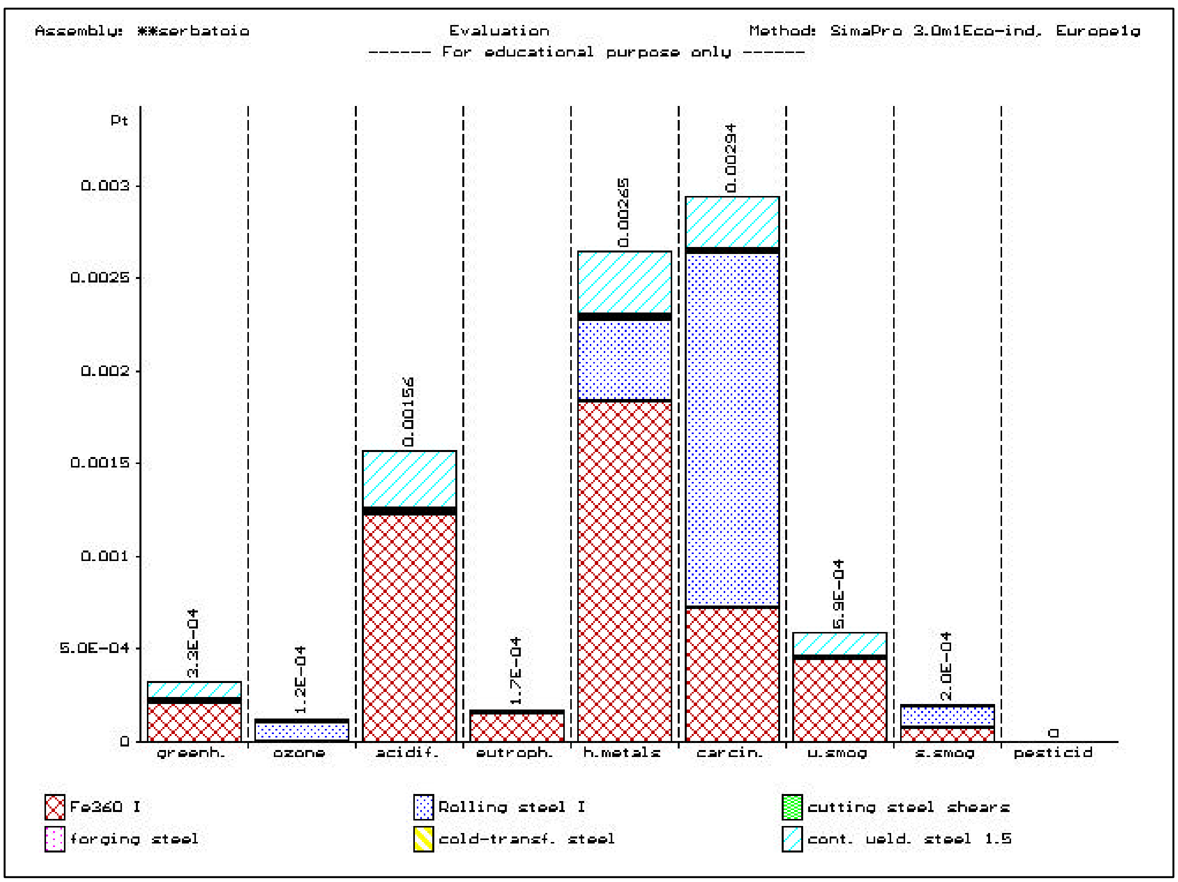


Fig.5 Evaluation by the Eco-indicator 95 method of the tank 'assembly'



3.5. Life cycle analysis by the Ecopoints method.

For comparison the life cycle analysis of compressor has been performed also by means of the Ecopoints method. The Tab. 3 shows the results.

Tab.3 LCA of the compressor by the Ecopoints method

CHARACTERISATION		
Damage categories	**Values**	**Damage causes and components**
Compression group		
Energy	474 MJ	Metal production and processes for stator and rotor
CO_2	43.2 kg	Metal production for stator, rotor and cylinder
Solid	24 kg	Material production for stator, conveyor and cylinder
Tank group		
Energy	85MJ	Production of paint and roads and feeding cable
CO_2	23.6kg	Material production for tank, roads and feeding cable
Solid	8.23 kg	Copper production for feeding cable
NORMALISATION		
Damage categories	**Values**	**Damage causes and components**
Compression group		
Zn(air)	98.48	Casting process for stator, cylinder and rotor
As(air)	0.213	Metal production for crankshaft and casting process for stator and rotor
Solid	0.2	Metal production for stator, cylinder and crankcase
Tank group		
Zn (air)	0.643	Casting process for pressure switch and clack valve
As (air)	0.395	Metal production, welding process and recycling for tank
Cd (air)	0.276	Material production for tank and pressure switch
EVALUATION		
Damage categories	**Values**	**Damage causes and components**
Compression group		
Zn (air)	15.1 Pt	Casting process for stator, cylinder and rotor
SO_2	0.613 Pt	Metal production and processes for stator, rotor and crankshaft
As(air)	0.372 Pt	Metal production for crankshaft and casting process for stator and rotor
Tank group		
Zn (air)	1.02 Pt	Casting process for pressure switch and clack valve
SO_2	0.646 Pt	Metal production and processes for tank and feeding cable
Cd (air)	0.577	Material production for tank and pressure switch

The Fig.6 and 7 show the evaluation by the Ecopoints method of the assemblies of the components that produce the greater damage.

Fig.6 Evaluation by Ecopoints method of the 'assembly' of the aluminium part of the stator.

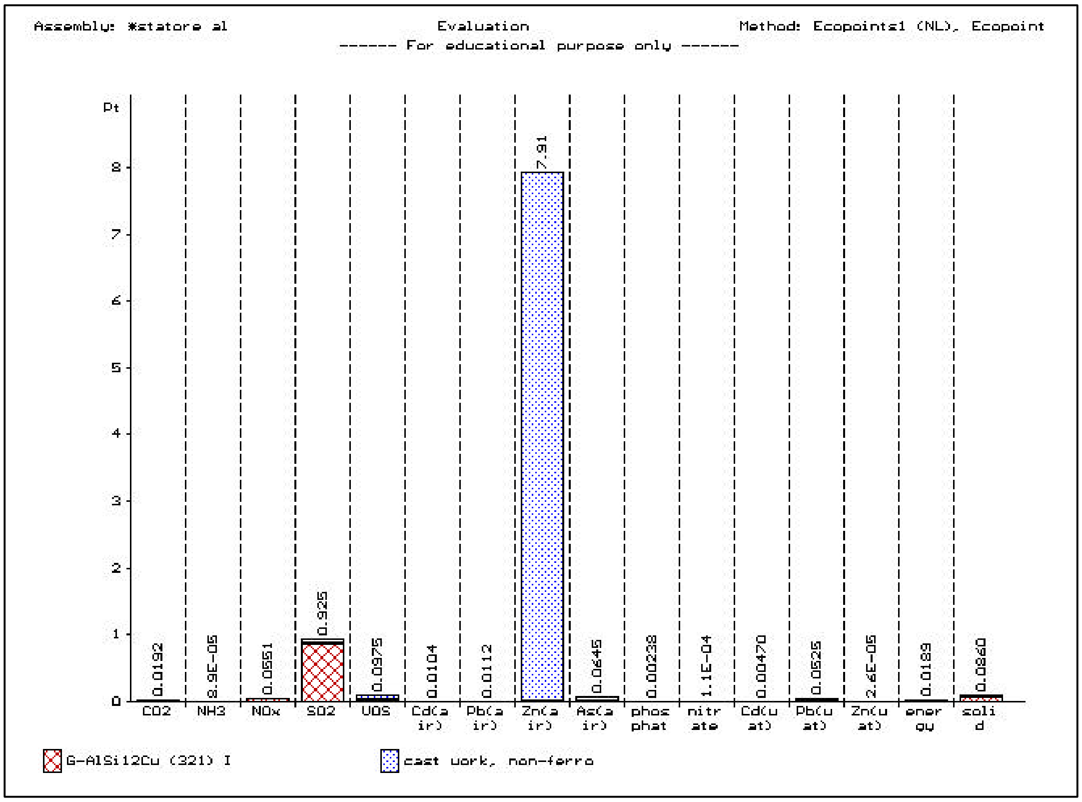
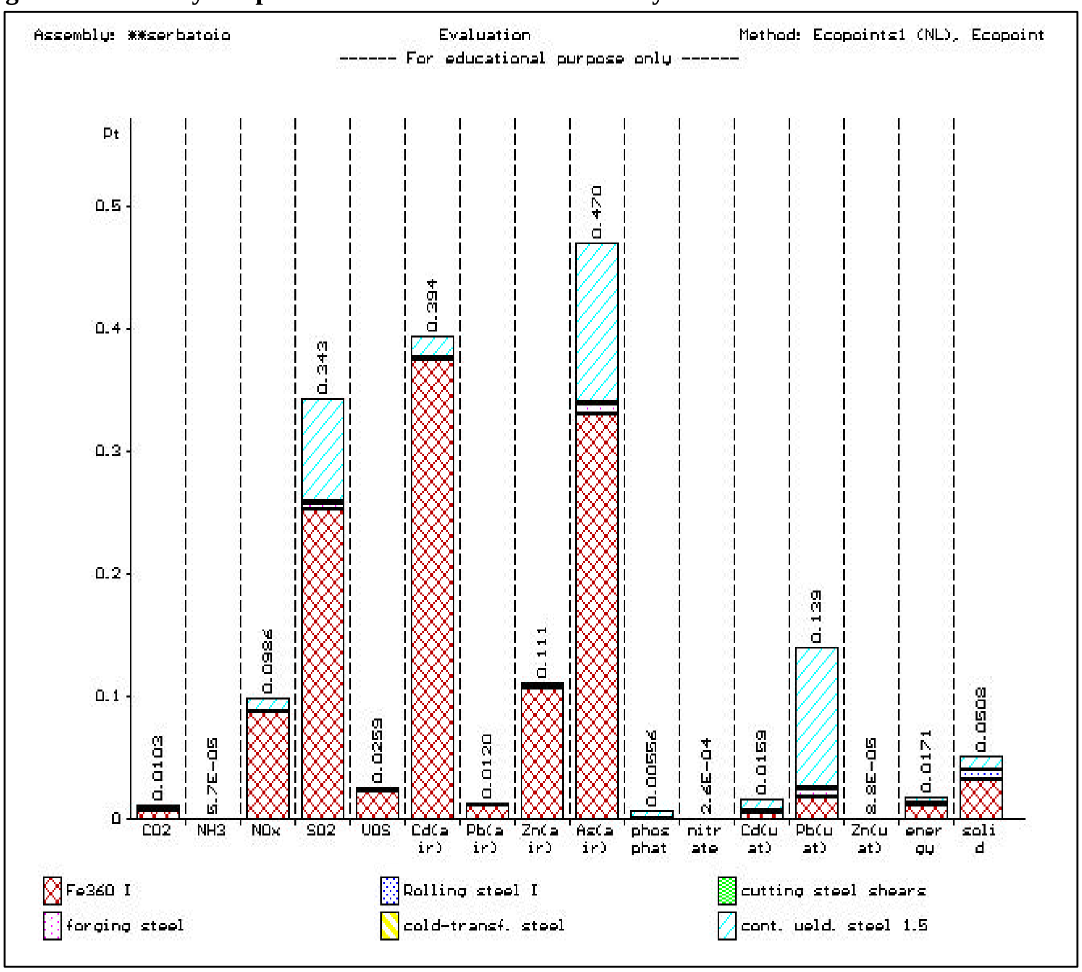


Fig.7 Evaluation by Ecopoints method of the tank 'assembly'



3.6. Comparison between the two method results .

The results obtained by the two methods are compared in percent terms because the two methods consider different damage categories and weight factors.

The Tab. 4 shows the results related to the energies, transports, component groups, packaging and auxiliary materials that compose the compressor LCA.

Tab.4 Comparison between the two method results.

Compressor LCA	ECOPOINT	ECOINDICATOR
Electricity Italy for Paint Electricity Italy for Indirect Centres Electricity Italy for Assembly	0.044%	0.057%
Electricity for Use	95.6%	98.38%
Transports for Distribution	0.16%	0.33%
Transports for Service	0.014%	0.03%
Compression group		0.52%
Tank group	0.64%	0.65%
Packaging	0.012%	0.012%
Auxiliary materials	0.014%	0.021%
Total damage	**499 Pt**	**1608 mPt**

As we can observe by the Tab. 4, the results show that the maximum damage is due to the energy consumed during the compressor use.

The damage due to the electricity for use obtained by Ecopoint method, affects with a lower percentage than the one obtained by the Eco-indicator method; the compression group has an impact that is proportionately over five times greater than the one calculated by the Eco-indicator.

This result is due to the fact that the Eco-indicator method does not consider emissions of some dangerous metals. For example the heavy metals category in Eco-indicator 95 method does not consider the emission of zinc neither in air nor in water and the emission of arsenic in air, while the Ecopoint method considers the heavy metals singularly.

3.7. Conclusions

From the results of the compressor LCA we can draw the following conclusions:

- the parts of the compression group with the highest environmental impact are the stator and the rotor.
- The parts of the tank group with the highest environmental impact are the tank and the pressure switch.
- The most relevant part of the damage is due to electrical energy consumed during use.

4. THE QUANTITIES OF MATERIALS, PROCESSES AND ENERGIES WITH DAMAGE EQUAL TO THE ONE OF THE COMPRESSOR.

By using the Eco-indicator 95 Europe g method we have calculated the quantities of materials, processes and energies that produce a damage equal to the compressor one. We have obtained that the compressor studied produces the same damage due to:

- a petrol car that travels 50 times from Bologna to Naples (distance of 800 km)
- a refrigerator with capacity of 250 l during 17.5 years of working
- a washing machine with the power of 1.5 kW during 2572 cycle of working
- a boiler with capacity of 80 l during 1462 cycles of water heating
- a production of 80400 kg of paving tiles, 5025 kg of paper, 4279 kg of iron and 893 kg of aluminium.

5. SOME PROPOSALS OF MODIFICATIONS OF THE COMPRESSOR DESIGN.

In order to improve the environmental capability of the compressor we have done some proposals of modification of its design. On the basis of the results of the LCA calculation we have identified the following options:

1) reduction of the air temperature both in the cylinder and at the exit from the manifold.

2) Improvement of the global efficiency of the compressor.

5.1 Reduction of the air temperature.

The reduction of air temperature can be obtained by means of the following solutions:

- by increasing the surfaces of the finning of cylinder, head and collector
- by finning also the pipe of delivery from the collector to the tank
- by increasing the surface of the delivery valve
- by increasing the quantity of air conveyed to cylinder and head by a new design of the blades of the ventilator[3].

We suppose that these modifications produce a decrease of electricity consumption of 3% and can be obtained by increasing the weight of the compression group of 5%. The LCA calculation points out a reduction of the damage of 3%.

5.2. Improvement of the global efficiency of the compressor

The improvement of the global efficiency of the compressor can be obtained by the following solutions:

- by increasing the finishing grade of the moving parts in contact
- by reducing the weight of the moving parts
- by increasing the seal of the pipe connections.

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